5.3.1 Special Procedures for Plugged Nozzles

Plugging of nozzles during jet grouting was an expected event based on past grouting experience (Loomis 1997, 1999). Plugging can occur due to intrusion of wet clay into the nozzles during the drilling sequence but can also be accentuated by grouts that filter cake. Another common source of plugging is debris within the grout delivery system all the way from the delivery truck to the pumping equipment. In the past (even in hot applications—Loomis 1999), there was always a trickle-flow of grout allowed. However, because of the use of the glovebox-like system in the thrust block using the plastic sleeves, the trickle flow was stopped, and the system was allowed to drain between grouting holes. Special testing was performed during the implementability testing and it was found that in the 1 to 5 minute timeframe the grout had drained to the point where no trickle flow of grout was observed. Therefore, the procedure was to stop all active pumping of grout and allow the system to drain into the thrust block. Until visually using the remote camera under the thrust blocks, no flow was observed coming out of the drill stem.

If in the event that a nozzle plugged, rotopercussion of the drill system was to be used until the nozzles were clear of debris or grout. If that failed, a complete new drill string/shroud assembly was to be employed and the old assembly taken to a separate area (simulating an adjacent glovebox) and the nozzles cleared. During the special System Operations testing at the shroud manufactures plant, it took nominally 1 hour to replace the old shroud with a new one. Once cleared, a new plastic bag was attached to the bottom of the drill assembly and the outside of the bag decontaminated. To this end a total of three complete drill string shroud assemblies were fabricated and on hand for the testing procedure.

Grout Mixing at Batch Plant

Grout was mixed in Idaho Falls-50 miles from the Cold Test Pit South in a specially designed batch mixing plant shown in Figure 46. The system involved mixing dry ingredients of GMENT-12 with water in a high shear mixer also shown in Figure 46. The mixture was transferred to Ready Mix trucks (clean-new dedicated trucks for this project). Grout was delivered in 3,024 L (800 gal) batches three times a day. Since each hole was to use nominally 378 L (100 gal) of grout it was possible to support grouting up to 24 holes per day. Enough dry ingredients were purchased to support 7 days of grouting operation. Since it was planned to only grout 114 holes (which would in a perfect application take nominally 5 days) there was an extra 2 day's supply of grout at three loads per day. In short, there was nominally an extra 18,144 L (4,800 gal) of grout that could be wasted during the anticipated 5-7 days of operation.

Table 31 contains a summary of the detailed mixing operations.

Table 31. Summary of GMENT-12 grout batch mixing times and grout data.

Mix Date	Batch Invoice No.	Plant Departure Time	Job Site Arrival Time	Marsh Funnel Time (sec)	Grout Specific Gravity
October 11, 2001	16669	8:40	10:05	52	1.86
October 11, 2001	16690	13:22	14:40	57	1.87
October 12, 2001	16697	6:49	8:00	51	1.85
October 12, 2001	16713	10:35	12:00	61	1.87
October 12, 2001	16738	14:13	15:30	60	1.87
October 15, 2001	16772	6:55	8:00	55	1.87

All batches were 4.0 yd^3.

Figure 46. Batch mixing operation (Photo PN01-0520-8-9A).

The dry grout product was mixed with water using a HighShear® 1,000 grout mixer with two MK 2 Colcrete colloidal mixers each driven by a 30 HP electric motor. The dry grout was weighed using a portable batch plant provided by Valley Ready Mix, Inc., and the water volume was measured using a Fill-Rite Series 900 flow meter supplied with the grout mixer. Prior to production mixing, a test batch was prepared to verify the accuracy of the mix proportioning. The specific gravity of the mixed grout is used as a quality control parameter to insure that the desired ratio of water to dry material is achieved.

During grout production, the grout is mixed in 1.33 yd^3 batches. The desired amount of water is added to the grout mixer through the flow meter. Once the water in the mixer has flooded the pumps and has risen above the pump inlet, the pumps are started and the addition of the dry grout material is initiated. The addition of water is stopped upon reaching the desired volume. Mixing of the grout continues as the remainder of the preweighed dry grout material is added to the mixer. After addition of the water and dry material is complete, mixing continues until the mixture is free of any lumps of partially mixed material. With the high shearing action of the Colcrete colloidal mixers, the high flow rates, and the relatively low viscosity of the GMENT-12 grout, a strong vortex is formed in the grout mixer during mixing (see Figure 47). The vortex is very effective in drawing any poorly mixed materials through the high shear Colcrete colloidal mixers where it is thoroughly mixed with the water, producing a homogeneous product. Once all of the dry grout material is in the mixer, the mixing is completed in about 60 to 90 seconds, and the grout is ready to be discharged into a concrete truck for transportation to the INEEL Cold Test Pit site.

Three batches of 1 m^3 (1.33 yd^3) each were used to produce the 3 m^3 (4 yd^3) loads that were used for the INEEL Cold Test Pit project. After the three batches of grout were loaded onto the concrete truck, the grout was blended by the concrete truck. Following the blending by the truck, the grout was sampled and tested. The specific gravity and Marsh funnel time were determined and recorded on the batch ticket. A time stamp was placed on the ticked prior to the truck leaving the plant. Mixing, screening, and testing of a 3-m^3 (4-yd^3) batch took about 30 to 40 minutes.

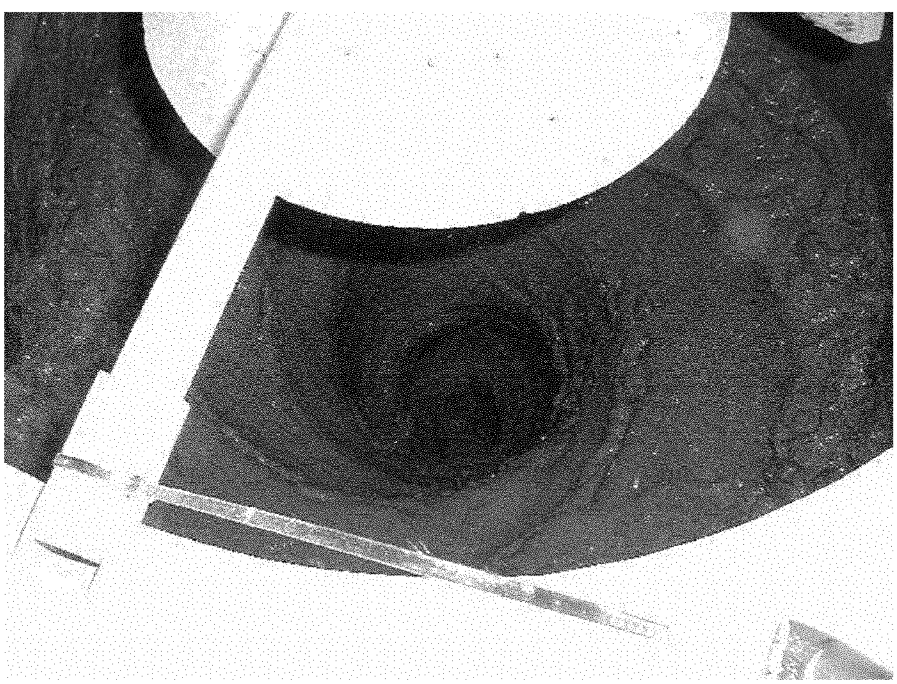

Figure 47. Grout mixer vortex view after 60 seconds of mixing.

Initially, the grout was to be screened as it was unloaded from the concrete truck at the INEEL Cold Test Pit site. When the first load was screened at the site, some unexpected material consisting of small hard fragments and fibrous material was retained by the screen. Subsequent batches of the grout were screened at the mixing location as the grout was discharged from the grout mixer into the concrete truck. The grout was passed through a double layer of standard wire window screen as it was loaded into the concrete truck. The foreign material is not usually found in the raw materials and has never been encountered in previous field or laboratory testing of the grout. The source of the foreign material has not been positively identified at this time.

5.4 Evaluation of Grouting Operations

In 2 days, a total of 12 holes were successfully grouted with 4,936 L (1,306 gal) of grout injected into the void space of the pit as shown in Table 32. This grout was emplaced into the voids of the pit with minimal grout returns; therefore an average of 408 L (108 gal) of grout was delivered in each hole and there was nominally 51 L (13.6 gal) of grout delivered per linear foot of waste. There was an attempt to grout the 13th hole at the end of the second day of grouting but this hole was abandoned due to plugging of the nozzle. At the start of the third day of grouting, the operation was terminated when attempting to grout the 14th hole due to an injury accident to a grouting subcontractor. A high pressure fitting at the exit to the pump catastrophically failed causing a piece of the fitting to strike the subcontractor with a resulting serious injury accident (see following section on lessons learned).

What follows is a description of the grouting process for the 12 holes leading up to the accident. Complete logbooks for the grouting operations are contained in ER-004-02. The thrust block filling operation described above was not performed and only a limited amount of contamination control data was obtained; however, a large body of operating experience was obtained prior to the accident in a limited amount of holes grouted and this information is contained in this section.

Grouting started on hole number 1 as shown in the schematic in Figure 37. The first 6 holes were considered edge holes, and for these holes the plan was to inject a lower amount of grout in that the hole spanned the edge of the pit and was a mixture of pure soil with low voids and debris waste with considerable voids. For holes in the interior, there were expected to be mostly debris type material with considerable voids. Appendix G contains an analysis of the expected void fraction and concluded that in general, there would be an expected void of 60%. Therefore, during the grouting campaign, it was planned to attempt to fill the pit with 60 to 70% of the volume of the pit using the 114 holes. What would dictate a local change to that rate of filling would be the amount of grout returns observed using the remote TV camera. If the returns became unacceptable (enough to fill the void space locally with a viscous return of grout and soil/waste mixture) then the grouting operation locally would be terminated and moved to a new hole.

The relative humidity and temperature of the air for the thrust block HEPA filtration system were continuously measured and it was found that at the start of each day, the humidity was higher and as the air flow continued under the thrust block, the humidity reached a lower steady state. On the first day the humidity was measured at 89% and 54°F and during the day it reached a more or less steady value during grouting of 69% Relative Humidity and 58°F. During the second day, the Relative Humidity continuously decreased as the day wore on with the first reading upon turning on the fans was 98% Relative Humidity reducing to around 67% Relative Humidity by the end of the day with 14°C (57°F). This high relative humidity at the start of the day followed by lower values as the day wore on is basically attributed to the airflow removes fluid from the air. From an operational standpoint, using water based grouts does raise the humidity and the system when continuously running has a nominal 67% Relative Humidity which must be factored in to HEPA filtration system designs.

Table 32. Summary of grouting during field testing (3.78 L/gal).

Hole	Elapsed Time	Grout Delivered	Pressure at the Pump	Grout returns	Comments
1	First hole of day-29 minutes from start to finish	129gal/4s/step	400 bar	None	Observed a 2-minute drain of the nozzles using the remote camera
2	44 minutes	135gal/4s/step	400 bar	None- a pint of neat grout came up to the surface as the drill string was withdrawn but the material went back down the hole	Took 34 minutes to reposition the drill stem and attach the plastic sleeves. The plastic sleeve with about 2.5 gal of neat grout fell onto the top surface of the thrust block when moving to hole number 3. Area was decontaminated.
3	80 minutes (includes cleanup time for spill)	120 gal/3.5s/step	400 bar	None	No problems; various solutions to the drain of the drill steel discussed
4	82 minutes	114 gal/3s/step	400 bar	None	Nozzles plugged-used rotopercussion to unplug them. Resistance in drilling at 2 ft into waste and 3.5 ft into waste
5	51 minutes	113 gal/3s/step	400 bar	1-quart of viscous grout returns possibly in a nitrate drum	The grouting was split as the nozzle plugged after grouting a few feet. The nozzle was unplugged by using rotopercussion. Small drip of neat grout as draining of drill steel incomplete and grout fills the bottom of the bag

Table 32 contains the data on the grouting operation for the first 13 holes. Basically the operation was progressing as planned with several exceptions as discussed below. There was an efficiency of operation realized as the process proceeded in that there was a marked decrease in the time to grout a hole as the process proceeded from hole 1 to hole 13. It appeared that all 114 could be grouted using the technique involving the thrust block as planned. The following issues arose during the grouting process of the first 13 holes described in Table 32 and (ER-004-02) contains a detailed log book of all major data taken during the field testing:

- Debris in delivered grout
- Draining of the excess grout in the drill stem, spillage of neat grout on the top surface of the thrust block, draining the drill stem of grout utilizing an air bleed point
- Expediting the time to perform the grouting process/wasted grout
- Plugging of the injection nozzles
- Plugging of the injection nozzle with lost time to relieve pressure
- Complete detachment of the inner and outer flexible hose on the shroud assembly, filling of the lower HEPA filter on the drill string shroud with grout, deterioration of the inner shroud due to mechanical contact with the drill string
- Collapse of outlet air line in HEPA filtration system for the thrust block
- Limited view of volume under the thrust block because of length of camera stem relative to the Lexan tube.

5.4.1 Debris in Delivered Grout

During delivery of the first two loads of grout there was considerable small debris observed on the screen at the entrance to the vortex mixing system. In fact, the debris was considered a serious enough problem to preclude jet grouting with the relatively small 2.4-mm nozzles used for the GMENT-12 grout. This was particularly puzzling to the grout vendor in that new delivery trucks were utilized for this project. The solution to the problem was to double screen the material at the batch plant. Upon a closer examination of the material on the screen, it was determined that it looked like material from a mouse nest that had collected in a pump somewhere in the system. After the raw material was double screened at the plant, the quality of the grout product delivered to the site improved.

5.4.2 Draining, Spillage, Cleaning

During implementability testing, once the drill string was brought to the surface, the draining of the drill steel of excess grout was timed and it was found that the grout drained out in the 1 to 5 min time period. Therefore during the field testing it was planned to allow a 5-min drain of the drill steel after the nozzles were brought to the space under the thrust block and in direct line with the remote TV cameras. After the first hole, it appeared that the drain time of a few minutes would allow essentially a complete drain of the drill stem and thus the taped plastic sleeve would not fill with grout and cause spillage onto the top surface of the thrust block.

Following successful grouting of the first hole, testing proceeded without note to the second hole and the same procedure was followed (i.e., allowing a few minutes of draining coordinated by viewing the nozzles with the remote TV camera). During the move between hole 2 and hole 3, the taped and twisted plastic sleeves filled with grout to the point that the frictional fit of the sleeves on the stinger caused by the plastic ties was insufficient to hold the head of grout and the sleeve fell off the stinger. About 2 L of grout spilled onto the top surface of the thrust block. From a contamination control standpoint, spilling neat grout that had been in contact with the nozzles and corner drive point was a potential disaster. However, the spillage was indeed neat grout that had been in the clean drill steel and the only chance of contamination was dripping of grout down the outside of the drill steel or small amount of contaminants that were in the nozzle area. Terbium contamination dripping down the outside of the drill steel was unlikely considering the extensive wipe that had occurred as the drill string was withdrawn across the wiper material in the bottom of the thrust block. In addition, the first and second hole both were on the edge of the waste and there was a high probability that the drill string had not encountered the terbium tracer. Therefore, the drill steel was rebagged and the area was deconned with Chem-Wipes and water and grouting proceeded to the third hole. When grouting the third hole, an attempt was made to allow more time to drain the drill steel and rotopercussion was applied until draining of drill steel seemed likely. This process took up to 15 minutes while watching progress under the thrust block with the remote TV camera. In addition, it was decided to tape the bottom of the cut twist-off sleeve to avoid leakage of grout onto the top surface of the thrust block. As an added precaution a separate plastic bag was also taped to the bottom of the twist off area.

As grouting proceeded, it became apparent that the system required a bleed point in the line to break the vacuum holding up the fluid and indeed that was implemented with positive results. The line was broken at a hose connection where the high pressure hose entered the tent. In addition to a simple bleed, compressed air was also blown into the line thus completely clearing the line of fluid between moves. This temporary fix was employed for the remainder of the holes; however, it was recognized that it was only a temporary fix for the treatability study. What was needed was a positive high pressure bleed value in the high point of the drill system swivel (where the hose interfaces with the drill steel). This would require a design and fabrication effort beyond the scope of the treatability study.

5.4.3 Excess Time to Perform Grouting/Wasted Grout

From a time-motion standpoint, the time to perform the grouting operation improved as the number of holes progressed. The early holes proceeded slowly with the first 6 holes taking an average of 53 minutes and the last 4 holes took an average of 37 minutes. The very first holes took up to 80 minutes per hole but as the process progressed, the last holes grouted took on the order of 30 minutes. This improvement reflected the learning curve on the combination of placing the plastic sleeve on the stinger, drilling/grouting/draining, and twisting off the sleeve and cutting the taped area. Further expediting could be accomplished by using only one plastic tie on the double bag rather than the two that were used for the first 13 holes which could reduce the time to around 25 minutes per hole. Change out of the drill string shroud was performed just prior to the accident. It took 1 hour and 10 minutes to remove the shroud and another 30 minutes to rebolt the shroud in place. It was obvious that the operation could be performed in a few minutes if the mounting system utilized an alignment bar and easier access to the bolts (this also applies to the HEPA filter mounting bolts). This operation was performed with a crew for the first time and they were basically on a learning curve for the shroud replacement.

Grout was to be delivered three times a day 3024 L (800 gal) at a time. The grout was mixed in Idaho Falls and delivered in Ready Mix trucks and there was a lead time of at least 2 hours to order a new batch. In other words, depending upon what was happening 2 hours prior to delivery was expected, the grout had to be mixed and delivered. What would happen is that problems would develop during that 2-hour window and in the extreme case, the on site delivery truck had not delivered any grout to the pumping equipment at the time the new truck came. This resulted in multiple dumping of full trucks of grout during the 3 days of grouting. In fact, there was 18,144 L (4,800 gal) delivered and only 4,936 L (1,306 gal) injected. What was needed was a portable ready-mix plant at the Cold Test Pit South.

5.4.4 Plugging of Injection Nozzles

Plugging of the injection nozzles is an inherent weakness for the in situ grouting in that grouting particulate grouts there is a potential for "filter caking" or deposition of particulate in low cross section regions such as nozzles. In addition, there is a tendency in clay soils to mechanically plug the nozzles with wet clay during the downward drilling process. In past demonstrations, to combat this tendency, a trickle flow of grout was maintained when moving from one hole to another. In the earliest tests, this small trickle of grout was simply allowed to freely flow over the grouting area but in a hot treatability study in the Acid Pit (Loomis 1999), a cone and catch cup was placed around the drill steel which allowed the flow but contained it to the catch cup. In all other prior grouting demonstrations and treatability studies, there was physical access to the nozzles and clearing of the nozzles usually involved simply lowering the pressure in the system and clearing the nozzle with a simple thrust of a piece of wire. However, in the current treatability study with the "glovebox" concept, there were two drawbacks:1) since the system was sealed by the twist off of the plastic sleeve, trickle flow was not allowed because there was no volume to collect this trickle flow during the extensive time period between holes and 2) because of the glovebox nature there was no access to the nozzles for physical removal of the plug. Because of this, considerable plugging of the nozzles occurred which caused much of the delays. Interesting enough, much of the plugging was cleared by utilizing rotopercussion of the drill system while the nozzles were under the thrust block and visible to the remote TV cameras. However, after grouting 12 holes, an attempt was made to grout the 13th hole and plugging occurred which was not clearable by using rotopercussion. What was used during the first 12 holes was a combination of short bursts of pressure from the high pressure pump combined with rotopercussion as the drill stem was inserted into the waste. Since it took nominally 1 hour to replace the drill string/shroud assembly, it was desirable to develop a technique to clear the nozzles by mechanical insertion of a wire perhaps in a special glovebox adjacent to the drill/grouting operation.

5.4.5 Plugging of Injection Nozzle with Lost Time to Relieve Pressure

As mentioned in the proceeding discussion, plugging of the nozzles was a common occurrence and the technique of pulsing the high-pressure pump while applying rotopercussion to the drill stem was routinely applied as the drill stem was inserted. When grouting hole number 13 this operation resulted in a nozzle that would not unplug and the system was pressurized to 500 bar (7,500 psi). The subcontractor procedure for this relatively dangerous situation is to relieve the pressure gradually by opening a relief bolt in the manifold immediately adjacent to the pump. After considerable effort involving approximately 1 hour of gradually relieving pressure on the system, the system was once again readily to grout, however, no amount of rotopercussion could break loose the nozzle plug and an attempt on grouting hole number 14 was abandoned.

5.4.6 Detachment of Shroud, Wearing of Material on Shroud, HEPA Filter Clogging

During the second day of grouting (holes 8-14), a slight detachment of the top shroud was observed and the system was moved outside the weather structure and the area taped with duct tape for completion of the days work with the understanding that there would be a shroud change-out before starting the next days work. The fact that the weld broke at the top was very confusing in that it was considered to be a non-moving part with little stress. At the end of the day, it was decided to install a new shroud assembly and destructively examine the old shroud assembly. Two findings were evident, 1) the inner and outer shroud weldment had broken most likely due to the extensive rotopercussion applied during the grouting operation, and 2) the inner shroud material had indeed worn against the rotating drill stem near the bottom as the drill was inserted. This was caused by an inherent twist in the shroud as the shroud was compressed. It was thought that by putting the proper twist in the inner shroud during construction could have circumvented this event. Another possible solution is to employ “spacers” in the design to keep the inner shroud from touching the rotating drive string. In addition, by using a better weld technique at the top, the weldments should have withstood the rotopercussion operation. After consultation with the manufacture of the drill string shroud, it was clear to them that a simple tack type weld was insufficient and a more robust weld should have been applied at this attachment point. Another interesting event occurred related to the shroud wear near the bottom. It was observed that when tipping the drill string to the horizontal positions which is done from time to time during normal operations, there was a filling of the bottom HEPA filter with fluid which rendered it ineffective. Once observed, the HEPA filter was changed out with a new one from one of the spare shrouds. Most likely, although not proven, fluid grout entered the space between the inner and outer shroud via the tear on the under shroud. It is unlikely that the fluid in the bottom HEPA system came from evaporated fluid under the thrust block in that during operation of the thrust block system, the relative humidity was measured at about 67% @ 57°F air temperature.

5.4.7 Collapse of Air Line in Thrust Block HEPA Filter

The air flow in the thrust block HEPA filtration system was adjusted to allow a negative pressure operation without a totally collapsed air line in the outlet of the thrust block. At first, the negative pressure under the thrust block was operated at 1.27 cm (0.5 in.) of Water which resulted in a complete collapse of the outlet line air hose. To avoid burning out the HEPA filtration pump, the negative pressure under the thrust block was cut back to the tenths of inches of water negative pressure. The range of operation for the first day of grouting was –0.076 to –0.152 cm (–0.03 to –0.06 in.) of water with most holes grouted at –0.03 in. of water. For the second day of grouting, the system range of –0.05 to –0.127 cm (–0.02 to –0.05 in.) of water with most of the holes grouted at –0.05 cm (–0.02 in.) of water. The problem with the outlet hose was that it was a collapsible plastic vent hose which would be better suited to a hard PVC piping type system.

5.4.8 Limited View of Volume Under Thrust Block

In general, the remote camera in the thrust block performed perfectly and gave a high quality video recording of the top surface of the soil under the thrust block. Since only the first few rows were grouted, there was no problems seeing the drill string go in and out of the ground and indeed, the removal of the plastic sleeve from the previously grouted hole was also visible. However, because of the length of the camera and the length of the LEXAN camera port as designed, there was a poor view of back rows of holes. What was needed was a deeper LEXAN well or a different camera design. In general, the camera provided invaluable feedback during grouting and would be considered mandatory for this type of operation.

5.5 Evaluation of Contamination Control

Contamination control of the finely divided plutonium particles was a central thrust of the treatability study. Operating with no spread of the terbium tracer above background was considered the performance standard of the thrust-block/glove-box approach. To assess this, a series of smears and air monitoring with high volume filters, were obtained as part of the grouting procedure. It was planned to take a smear sample of the top surface of the thrust block on every third hole grouted starting with hole number 1. Since the grouting process was truncated by the accident, only a small data set was obtained for this measurement. Other data included taking a smear sample on the inside surface of the drill steel (inside the shroud), a smear sample on the outside surface of the inner shroud, a smear sample on the inside surface of the outer shroud. Other data included an extensive background measurement for the local air for terbium tracer. A total of 11 individual backgrounds were obtained using the seven high volume samplers located around the thrust block and during grouting there was a composite of the 6 high volume filters taken for each day of grouting for comparison to the background. Finally, what little grout returns came to the surface were evaluated for the presence of total organic compounds and the terbium tracer as a stand-in for plutonium. There were several events that could have adversely affected the contamination control data (meaning terbium above background appearing on the top surface of the thrust block or in the air samplers). These events included a spill of neat grout as the twisted-off plastic sleeve filled with grout in the drill stem that was not drained and several minor drips of the same grout that occurred due to poor draining of the drill steel prior to the "bag-out" procedure.

What follows is a discussion of the results of the contamination control data.

5.5.1 Results of Thrust Block and Drill String Smears

Table 33 below summarizes the ICP-MS evaluation of smears taken before, during and after grouting. The smears were standard 100 cm^2 swipes of surfaces using a standard fiber smear material. Smears were taken on the top surface of the thrust block, the outside surface of the drill string, the outside surface of the drill string shroud, the outside surface of the inner shroud, and the inside surface of the inner shroud. When a value of the smear is expressed as less than 11.8 ng/smear it means the reading is at the detection limit for that run based on the use of known tracers in the ICP-MS system (see complete data set in Appendix L). Examination of Table 33 shows that the smears taken before grouting on most surfaces showed an ICP-MS reading of "less than 11.8 ng/smear except for one smear that had 16.3 ng/smear on the north edge of the thrust block. Either this was a residual particle of terbium from the pit construction process or a statistical representation of a real background. At this point, it is assumed to be the upper limit of background smears taken prior to grouting. In general the number is no higher than 11.8 ng/g.

The smear taken after grouting hole number 1 showed a similar terbium concentration as the background as expected. This was expected in that the glove sleeves on the drill string and drill string shroud were designed to contain the movement of any tracer. In general, however, after the plastic bag (formed by the twist-off of the plastic thrust block sleeves) filled with grout and fell onto the top surface of the thrust block, the smears taken on the top of the thrust block were elevated in terbium reading relative to the background. The readings for these post spill thrust block smears varied between 14.2 to 35 ng/smear compared to the background values of "less than 11.8 ng/smear." The spilled material was primarily neat grout; however, material on the outside surface of the thrust block was potentially contained terbium tracer due to the fact that the drill string was driven into the simulated waste containers and could have been immersed in neat grout held back by the bag. On a later chapter discussing the destructive examination of the limited monolith it is shown that a drum containing combustible had been punctured and grouted. Combustible drums contain 100 g of terbium oxide tracer.

Likewise, some of the smears taken on the drill string when drill string shroud no 1 was destructively examined show elevated values (12.2-32.2 ng/smear) as expected since the drill string was driven repeatedly through the simulated waste containing the terbium tracer. However, half of the readings on the used drill string were at background type levels indicating that the drill string wiper material was partially effective in wiping off the mixtures of soil and grout or mud-like material on the outside surface of the drill string.

Smears were taken before and after grouting on the surfaces above the grease seal at the top of the shroud and it was found that even though grease was present after use on this top surface, the after grouting ICP-MS terbium reading was at the background type reading. This is important in that it means the grease seal was working to contain the spread of terbium tracer around the rotating drill string.

It appears that even though the shroud basically separated at the top and was worn through the inner shroud as the drilling proceeded (due to rubbing of the inside surface of the inner shroud on the drill string), the smears taken on the inside surface of the outer shroud and the outside surface of the inner shroud showed only background type readings. However, when examining the inside surface of the inner shroud, the ICP-MS values of the smear was elevated (21.8 ng/smear) relative to background as expected.

In summary, evaluation of the smears show that the shroud/thrust block contamination control system appears to work as designed as long as fluid in the drill string can be drained to disallow filling of the bag formed by twisting off the plastic sleeve containing grout. In addition, even though the inner shroud was worn by rubbing on the drill steel, there was not a spread of contaminants outside the shroud and the in depth contamination control strategy afforded by the thrust block/drill string shroud system worked as planned.

Table 33. Summary of ICP-MS evaluation of smears.

Location of Smear ($100\ cm^2$)	Terbium Concentration (ng/smear)
Thrust block background-north edge	16.3
Thrust block background-center	Less than 11.8
Thrust block background-south edge	Less than 11.8
Drill String Background no 1-entire surface	Less than 11.8
Drill String Background no2-entire surface	Less than 11.8
Drill String Background no 3-entire surface	Less than 11.8
Drill String Shroud Background –Shroud 1	Less than 11.8
Drill String Shroud Background-Shroud 2	Less than 11.8
Drill String Shroud Background-Shroud 3	Less than 11.8
Above Shroud Grease Fitting no 1	Less than 11.8
Above Shroud Grease Fitting no 2	Less than 11.8
Above Shroud Grease Fitting no3	Less than 11.8 plus dup at less than 11.8
On Top Surface of Thrust Block Hole#1	Less than 11.8
On Top Surface of Thrust Block Hole#3(near spill)	21.5
On Top Surface of Thrust Block Hole#4	35.2
On Top Surface of Thrust Block Hole#7	Less than 11.8
On Top Surface of Thrust Block Hole#10	14.2
Inside Surface Outer Shroud (Shroud no 1-shroud used for holes 1-12)	Less than 11.8
Outside Surface Inner Shroud (Shroud no 1)	Less than 11.8
Inside Surface Inner Shroud (Shroud no 1)	21.8
Collected above Shroud no 1 Grease Fitting –contained grease	Less than 11.8
Collected above Shroud no 1 Grease Fitting-second sample	Less than 11. 8
Top of Used Drill String no 1 first sample	Less than 11.8
Top of Used Drill String no 1 duplicate of first sample	32.2
Top of Used Drill String no 1 second sample	Less than 11.8
Middle of Drill String no 1 first sample	Less than 11.8
Middle of Drill String no 1 second sample	28.0
Bottom of Drill String no 1 first sample	Less than 11.8
Bottom of Drill String no 1 second sample	Less than 11.8
Bottom of Drill String no 1 third sample	12.2
Water sample from clean-out of first day's operation	0.88 ng/mL

5.5.2 Results of Contaminant Spread to the HEPA Filter

The HEPA filtration system for the thrust block was dismantled and samples of the filter were processed for ICP-MS evaluation for terbium tracer. Table 34 shows the results of this evaluation.

Table 34. ICP-MS evaluation of thrust block HEPA filtration system.

Location in Thrust Block HEPA Filter	Terbium Concentration (micro g/g)
HEPA prefilter 1	0.017
HEPA prefilter 2	0.038
HEPA prefilter 3	0.063
HEPA filter 1	0.177
HEPA filter 2	0.175
HEPA filter 3	0.174

This data set is inconclusive in that there is no established background sample for the ICP-MS; however, the data are presented as a reference for future reference for any follow-on work involving in situ grouting contamination control studies. It is noted that there is a large variation in the HEPA prefiltration in that the third sample shows a factor of almost 5-in. terbium concentration over the first sample. This indicates that most likely terbium tracer had advanced from under the thrust block to the prefilter of the HEPA filtration system. Also, since the three evaluations of the HEPA system are essentially identical, it is most likely that no tracer advanced past the pre filter material. Even thought the HEPA filter values are elevated above the pre filter values, this represents a variation in the ICP-MS process for digesting the filter materials in that the prefilter is of different material from the HEPA filter.

5.5.3 Results of Air Monitoring

During the grouting operation air samples were taken using seven strategically located samplers as shown in Figure 42. The filters used in these high-volume air samplers were composted and evaluated for terbium tracer using ICP-MS as one sample. The results were expressed as ng/g of filter per average cu. ft. of air that passed through the seven high-volume samplers. Table 35 presents the results of the ICP-MS evaluation for samples taken during grouting (one set of seven per day) along with 14 background air samples. The average or mean background reading of terbium concentration per air volume for the 14 backgrounds was 0.026 ng/g/cu. ft. of air with an average deviation from that mean of 0.0059 ng/g/cu. ft. of air. This means that the reading during grouting was between 0.015 to 0.0378 ng/g/cu. ft. then there is a 2-sigma or 95% confidence that the reading is at background levels. If the reading during grouting was between 0.02 to 0.032 ng/g/cu. ft. of air than there is a one-sigma or 67% confidence that the reading is at background. Examining Table 35 on Day 1 and Day 2 of grouting (0.015 and 0.012 respectively) there is a 95% confidence that the air monitoring at background levels meaning no spread of contaminants. This is significant in that there was a definite spill of potentially terbium contaminated material on the top of the thrust block during these two days of testing that could have dried and been aerosolized by the continual personnel travel on the top surface of the thrust block. For Day 3 (there was no grouting that day only set-up leading to the accident), the air monitoring reading was 0.021 ng/g/cu. ft., which is below the mean value of 0.026ng/g/cu. ft. The Day 3 value, however, is only within one sigma or 67% confidence that the reading is at background. It is noted that the drill string no. 1 shroud was mechanically disassembled exposing the drill string to the inside the weather structure at the end of the Day 2 grouting and this was a possible source of a higher reading than for Day 1 and 2, during which there was continual personnel traffic inside the weather structure and on the top of the thrust block that was not seen on Day 3.

Table 35. Results of air monitoring for terbium tracer (0.028 m^3 = 1 ft^3).

Sample Collection Period	Average Total Air Flow (ft^3)-average of 7 high volume filters	Terbium concentration in the composite filters (Ng)	Terbium concentration weighted by the Air Flow (ng/g- ft^3)
Background Run No. 1-9/13/01	6539	176.4	0.027
Background Run No. 2-9/13/01	6827	172.2	0.025
Background Run No. 3-9/18/01	6970	137.9	0.019
Background Run No. 4-9/18/01	6366	172.7	0.027
Background Run No. 5-9/19/01	7113	137.2	0.019
Background Run No. 5dup-9/19/01	7113	181.4	0.025
Background Run No. 6-9/24/01	7865	197.3	0.025
Background Run No. 7-9/24/01	6712	86.3	0.012
Background Run No. 8-9/25/01	9071	132.2	0.014
Background Run No. 9-9/25/01	6521	188	0.028
Background Run No. 10-9/26/01	9885	194.3	0.019
Background Run No. 11-9/26/01	5407	183.4	0.039
Background Run No. 12-9/27/01	7828	170.0	0.022
Background Run No. 12dup-9/27/01	7828	164.7	0.021
Background Run No. 13-9/27/01	7346	192.6	0.026
Background Run No. 14-10/01/01	8709	170.5	0.019
Sampling First Day of Grouting 10/11/01	15,404	233.6	0.015
Sampling Second Day of Grouting 10/12/01	17820	218.0	0.012
Sampling Third Day of Grouting 10/15/01	8772	191.0	0.021

5.5.4 Results of Contamination in the Grout Returns

Post grouting grab samples of returned grout material in the vicinity of select grout holes where obtained, analyzed by ICP-MS for terbium tracer and compared to a similar analysis for soil samples and a neat grout sample. Determining the terbium tracer content in the grout return samples under the thrust block reflects on the expected amount of contamination that might be expected during a hot operation. Table 36 shows the results of ICP-MS analysis for the common soil samples, neat grout samples and the grout return samples for holes numbered 5, 6, 7, 9, 10, 11,and 12. These holes displayed some visual evidence of grout returns using the remotely controlled camera and therefore were targeted for analysis.

Table 36. ICP-MS analysis of soil and neat grout backgrounds compared to grout returns under the thrust block.

Sample Location	Terbium concentration (Tb microg/g)
Surface Soil in Weather Structure	0.660
Surface Soil in Weather Structure	0.719
Average Soil in Weather Structure (background)	0.689
Neat Grout Sample 1	0.693
Neat Grout Sample 2	0.676
Neat Grout Sample 3	0.690
Average clean Soil/Grout Samples (Considered Background)	0.687+/-.013
Grout Return Hole 5(West Side of Hole)	0.686
Grout Return Hole 5 (East Side of Hole)	0.619
Grout Return Hole 5(SW side of Hole)	0.665
Grout Return Hole 6(N side of Hole)	0.673
Grout Return Hole 6(SW side of Hole)	0.665
Grout Return Hole 6(E side of Hole)	0.696
Grout Return Hole 7(E side of Hole)	0.660
Grout Return Hole 7(S side of Hole)	0.706
Grout Return Hole 7(W side of Hole)	0.668
Grout Return Hole 9 (N side of Hole)	0.702
Grout Return Hole 9 (E side of Hole)	0.649
Grout Return Hole 9(SE side of Hole)	0.667
Grout Return Hole 10(N side of Hole)	0.136
Grout Return Hole 10(SW side of Hole)	0.554
Grout Return Hole 10(E side of Hole)	0.696
Grout Return Hole 12(N side of Hole)	0.688
Grout Return Hole 12 (SW side of Hole)	0.808
Grout Return Hole 12 (NW side of Hole)	0.731

The surface soil samples and neat grout samples were averaged to obtain a background of 0.687 µg terbium per gram of sample (with an average deviation from the mean of 0.013 µg/g). Table 36 shows that for holes 5, 6, 7, 9,and 10, the readings for the grout return samples were at background meaning no release of the terbium tracer which is located in all containers except the nitrate salt drums. However, the measurement of the terbium content for hole 12 showed elevated levels (levels beyond the average background and average deviation from the average). It is noted that for hole 12 in Table 32, there was mention that a small, 15-cm (6-in.) cone of "viscous" returns came to the surface meaning that a simulated waste drum containing the terbium tracer had been hit. Grout returns showing terbium tracer were expected for all holes except the holes directly over the nitrate salts. Grout returns with terbium tracer was anticipated for those holes over an organic sludge drum (there was maximum terbium tracer and essentially zero voids in the organic sludge material).

The conclusion reached in this data is that the grout returns have the terbium tracer and if more of the pit had been grouted, it is anticipated that more of the returns would have shown tracer. The fact that holes 5, 6, 7, 9, and 10 show no tracer is mainly due to the fact that these first holes are more on the edge of the pit and further grouting would have shown movement of the tracer material to the surface in the form of grout returns.

5.5.5 Comparison of Clean-out to Background Water Samples

Clean water was used to clean the drill steel and originated in a Rain for Rent container. Background water samples from this Rain for Rent system were evaluated for terbium tracer and a comparison was made to a single data point obtained during the grouting operation of a drill stem clean out water. A single sample of the clean-out water was taken during the grouting operation and is reported in Table 33 as 0.00088 µg/g (0.88 ng/mL). When comparing the background water samples to this single data point, it could be concluded that there was terbium tracer in the clean-out water. However, the extremely small numbers reported in this background and in the clean-out water sample stress the detection limit of the system, and the conclusion is that "no terbium" is present in the clean-out water (see Table 37). To make definitive statements about terbium in the clean-out water would require a better statistic. During the Acid Pit Project (Loomis 1998) no contaminants were detected in the clean-out water and a similar procedure was followed.

Table 37. Summarizes the results of the ICP-MS evaluation of clean-out water samples.

Location of Sample	Terbium Concentration (µg/g)
Rain for Rent Sample no 1	Less than 0.0002
Rain for Rent Sample no 2	Less than 0.0002
Rain for Rent Sample no 3	Less than 0.0002

5.5.6 Discussion of Contamination Control Results

Although only a limited set of contamination control data was obtained due to truncation of the project, it is concluded that the contamination control system was working as planned. Terbium tracer was found in those parts of the system within the "glovebox" of the thrust block/drill string shroud assemblies but not on parts of the system associated with manned entry. The contamination control features of thrust block/drill string shroud concept worked as planned. There was no terbium tracer spread to the high-volume air monitors, even though neat grout with potential terbium contamination was spilled onto the top surface of the thrust block when the sack containing grout drippings fell off the drill string stinger. In fact, inductively coupled plasma-mass spectroscopy of smears taken on the top surface of the thrust block following cleanup of the spill showed terbium contamination. However, even with eventual extensive foot traffic and movement of the drill rig, there was no spread to the high-volume filters. The idea is that the grout locks the tracer material up in larger, less easily aerosolizable particles. It is speculated that if the bag had not dropped, there would only have been terbium tracer within the containment of the drill string shroud and under the negative pressure of the thrust block.

5.6 Destructive Examination of the In Situ Grouting Pit

Using a backhoe with thumb attachment, the limited in situ grouting monolith (October 2002) was excavated, revealing a solid monolith with the usual inclusions of compacted clay soil. The shape of the monolith followed the shape of the holes grouted, which extended across the 4.5 m (15 ft) of the pit with the width of the monolith generally varying between 40-66 cm (16-26 in.) wide with the exception of the Northwest end of the pit. At this position a metal sided drum was embedded in a monolith and the width was 92 cm (36 in.) including drum and monolith. Based on records obtained during construction of the pit, this drum was determined to be a painted white metal-sided drum containing nitrate salts. The drum embedded in the monolith is shown in Figure 48.

The section exposed was just the top of an 8-ft monolith of grouted waste and represented only grouting in 12 holes (approximately 2 rows of 6 holes each row). To the backhoe operator, the monolith was obvious in that there was a large resistance to digging compared to the surrounding soils. Figure 48 shows the top of the top of the monolith. Figure 49 shows the same region during construction of the pit with the white metal sided nitrate drum in the left corner.

The white metal nitrate drum was removed for further examination and the surrounding grout actually adhered to the drum surface as shown in Figure 50.

Examination of the drum showed that the drum apparently was filled with grout. The drum lid was removed and the face of the contents looked like solid grout. The end was struck with a pick to a depth of about 12.7 cm (5 in.) until the "J" seal of the plastic sack within the drum was revealed completely embedded in what appeared to be neat grout. The end of the drum is shown in Figure 51.

The exterior of the drum was examined and it was determined that the drum had been punctured for only about 22.8 cm (9 in.) on the side of the drum. This puncture is shown on the left side of the drum in Figure 52. The cylindrical shape of the drill steel is shown on this picture. This hole corresponds to hole number 7 in which 393L (104 gal) of grout was injected in 8 ft of grouting. This corresponds to a maximum of about 1 gal of grout delivered for every inch of penetration; therefore, 22.8 cm (9 in.) of grouting in the drum could have involved the placement of about 34L (9 gal) of grout in the drum. It is possible that following grouting, more grout and soil/grout mix gravity fed into remaining voids in the drum.

A hole was made in the metal of the drum in the middle, and the contents were examined. This hole is shown in Figure 53. Also shown in Figure 53 are two holes on either end made by the backhoe during excavation. Contents of the drum observed in the end holes was neat grout and in the middle was a low compressive strength mixture of nitrate salts and grout. This suggested that the grouting action had penetrated to the center positions of the drum, even though the drum had been punctured on the edge.

The actual grout delivery to the interior of the drum had two sources: 1) the limited jet grouting in the maximum of 22.8 cm (9 in.) of travel of the rotating drill stem, and 2) any gravity feed of grout and soil/grout mixture that would have occurred after grouting. Most likely, the two tears in the metal sides showing "neat grout" represent a thin layer in which there were edge voids between the plastic sack and the inside diameter of the drum. Basically, the idea is that grout readily filled the top of the drum with a large void and other voids on the outside of the sack and the interior of the sack with the nitrate represent a very low compressive strength mixture of grout and nitrate salt. Nevertheless, the drum seemed to be embedded in a wall of the mixtures of soil and grout such that the grouted nitrate drum was part of the matrix.

The drum had been weighed prior to building the Cold Test Pit and the recorded weight was 173 kg (381 lbm). The drum was weighed following excavation and the drum weighed 204 kg (450 lbm), indicating that a total of 31 kg (69 lbm) of grout had entered the drum. The grout has a density of approximately 1.8 g/cm^3 (112 lbm/ft3) or 1.8 kg per liter (15 lbm per gal). This 31 kg (69 lbm) extra in the drum accounts for 17.3 L (4.6 gal) of grout delivered to the drum.

Figure 48. Top of monolith showing grouted drum embedded in northwest edge.

Figure 49. Top layer of in situ grouting pit during construction with white nitrate drum in corner.